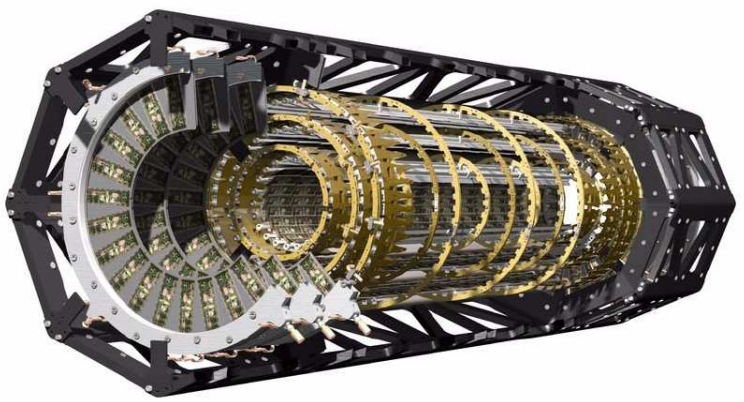
Results from the Commissioning of the ATLAS Pixel Detector



① The Pixel Package

② Installation and Connection

③ Calibration

④ Data Taking

⑤ Summary and Outlook

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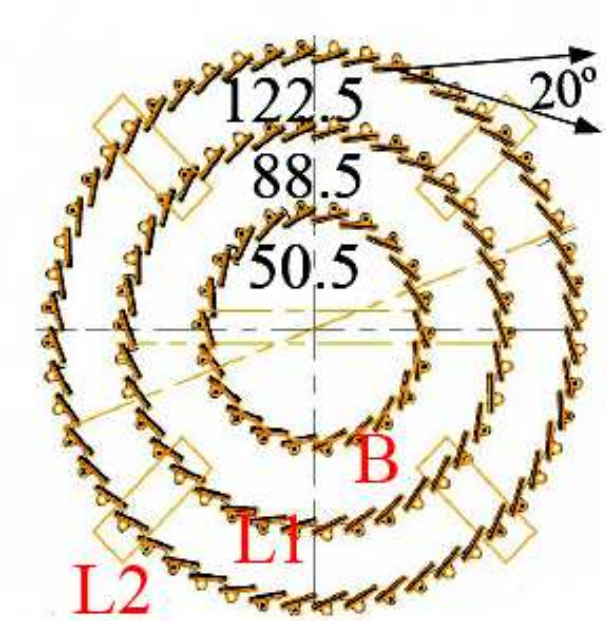
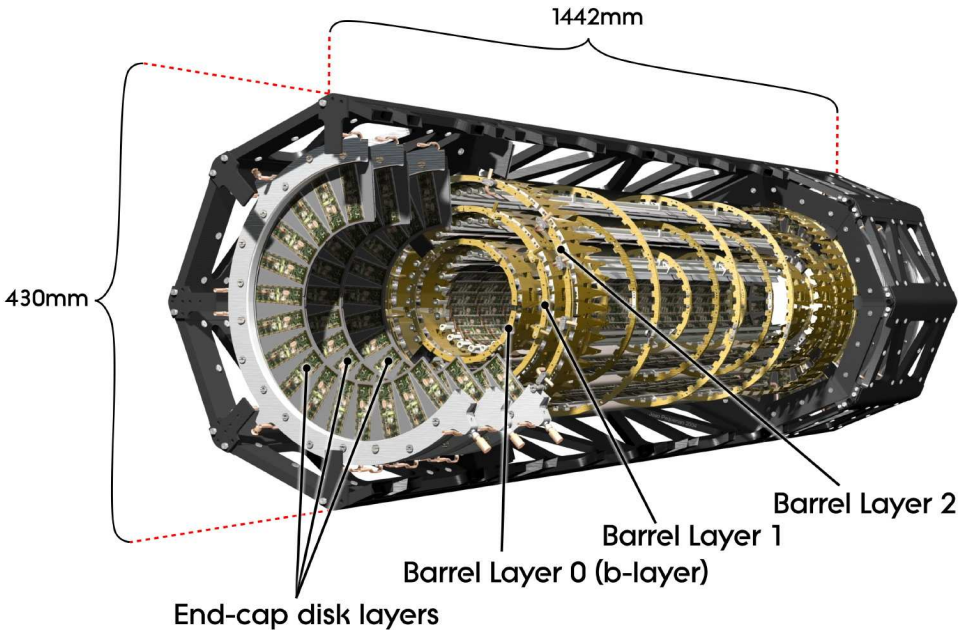
on behalf of the ATLAS Pixel Collaboration

Pixel Overview

- 3 layers, 2×3 disks.
- 1744 modules.
- 46080 channels/module.
- Total 80 M channels.

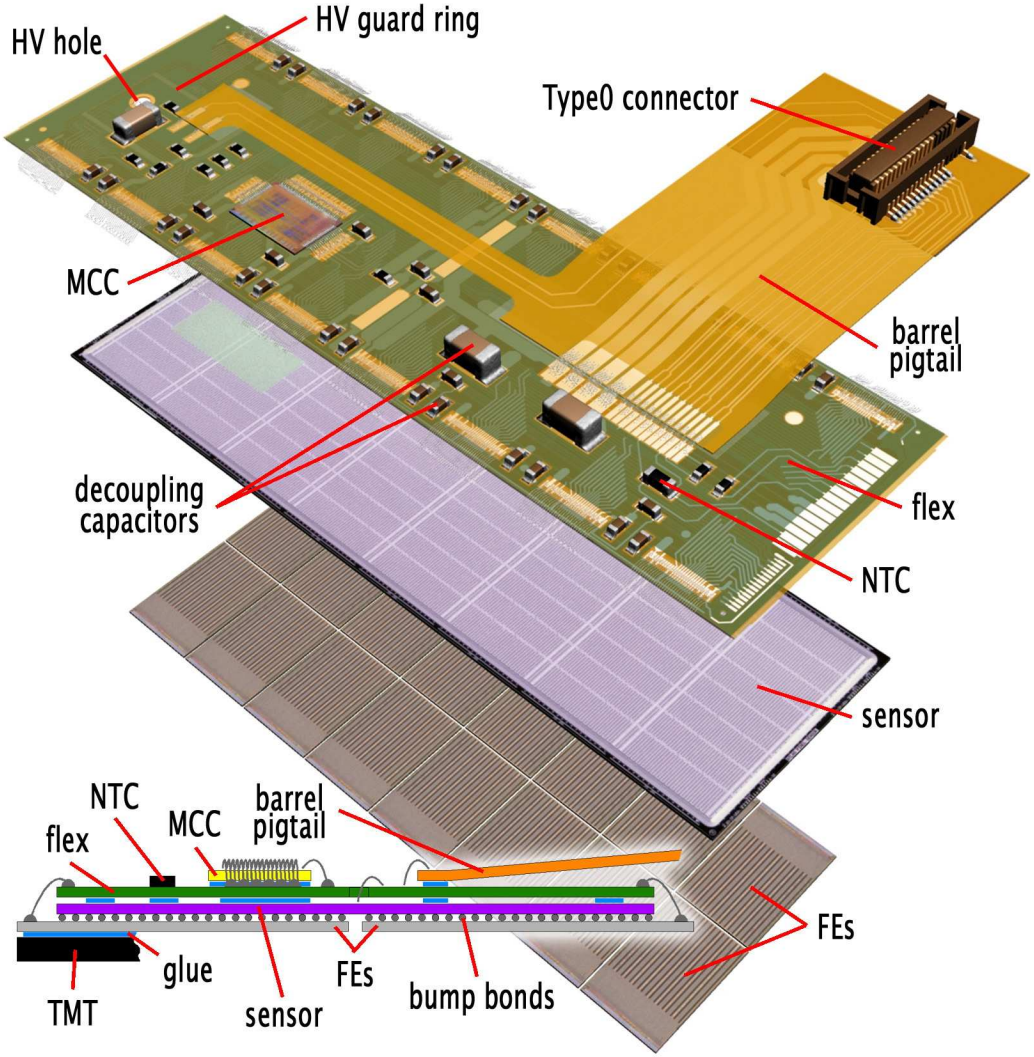




- Layer0 at 5 cm from beam pipe.
- Layer1 at 9 cm, Layer2 at 12 cm.
- Total active area ~ 1.8 m^2.

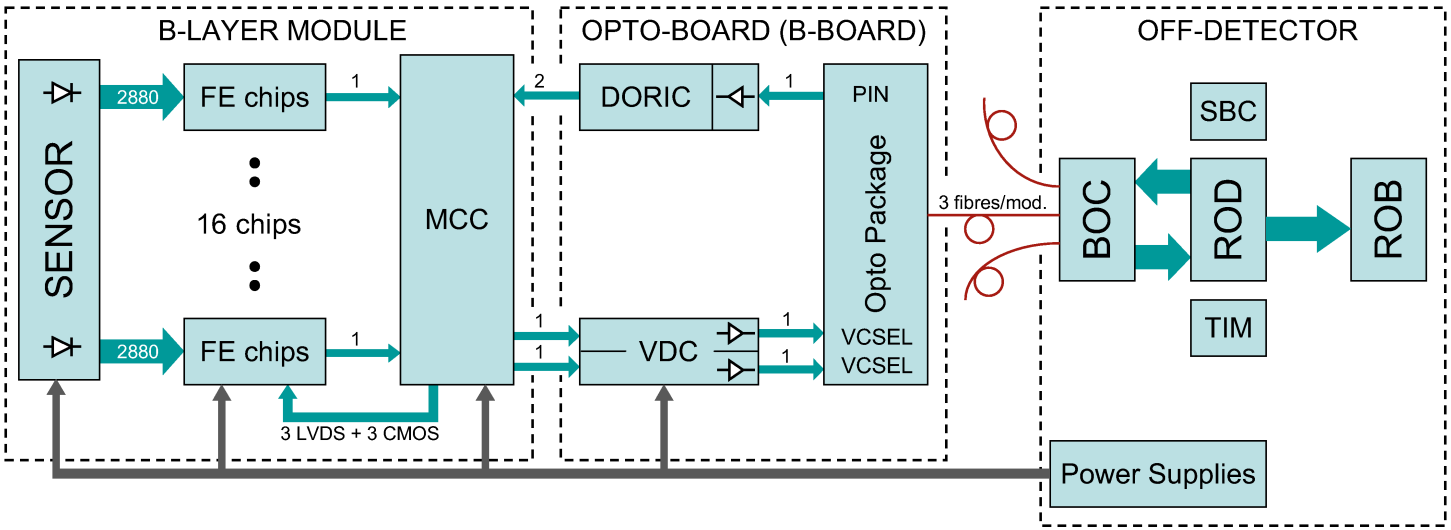
Modules

- 250 μm thick. n-doped bulk with n^+ pixels and p^+ backplane.
- Rad. hard to 50 MRad.
- Active are per module 60.8×16.4 mm.
- Sensor bump-bonded to 16 FEs (0.25 μm CMOS).
- FEs connected to MCC.
- Pixels at FE borders (in total 15 %) are special (long, ganged etc).



Readout Electronics

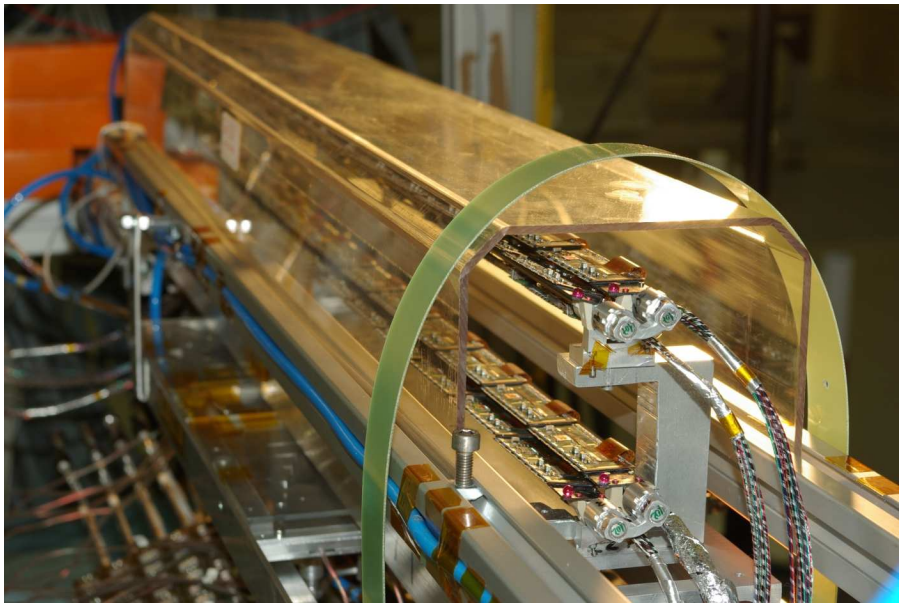
- Send data at 40 MHz (L2), 80 MHz (L1+disks) or 160 MHz (L0).
- Optoboard services 6/7 modules, converts between electrical and optical signals. VCSEL laser, PIN diode and chips.
- Back-Of-Crate card (BOC) does off-detector conversion between electrical and optical. Decodes into 40 MHz lines.
- ReadOut Drive (ROD) with FPGAs and DSPs.



Pixel Installation in June 2007

And Then We Waited - Test Stand

- On surface, assembled a small replica of the real detector.
- Made up of 90 modules
  - 5 % of the real detector.
- Hardware and software as close as possible to pit. But:
  - Fewer modules.
  - 2 (less populated) readout crates.
  - Simpler cooling.



- System has been proven extremely useful in software development and in understanding calibration procedures.
- Also used to understand hardware and develop test methods.
- Will continue to operate in parallel with the real detector.

Detector Sign-Off in Spring 2008

- Connection started on Feb. 6th 2008 and finished on April 18th.
- Electrical: Signed off during the connection.

$\Rightarrow$ 1 NTC and 6 HV opens.

- Optical Fibers:
  - Downlink signed off by sending light to the detector and measuring the PIN current on-detector.
  - Uplink signed off by asking modules to send back clock and verifying the signal in the readout crates.

$\Rightarrow$ Low or no light power on many downlink laser channels.

- Cooling: Signed off by loop-back and leak-down tests. Operating loops with different heat loads.

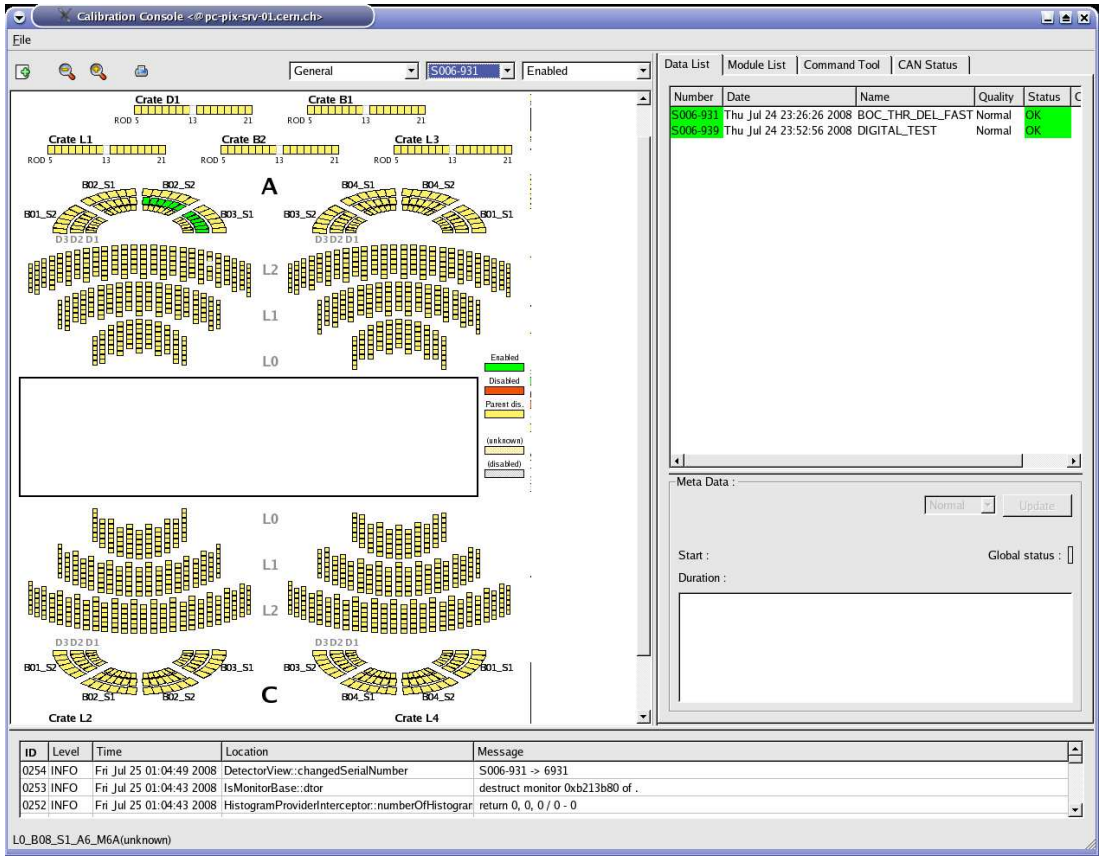
$\Rightarrow$ 3 leaky loops (36 modules). Some loops difficult to regulate.

Calibration Program

1. Tune the optical links.
2. Do digital injections to verify that we can send data without errors in the optotuned configuration.
3. Perform threshold scans with and without HV to
   (a) determine threshold per pixel and the threshold dispersion.
   (b) verify that modules are biased.
4. If the threshold dispersion is too large, perform a threshold tuning.
5. Do analog injections at 20ke to study TOT mean and dispersion.
6. If TOT dispersion is too large, perform TOT tuning.
7. Derive full TOT-vs-charge calibration using analog injections.

Calibration Procedure

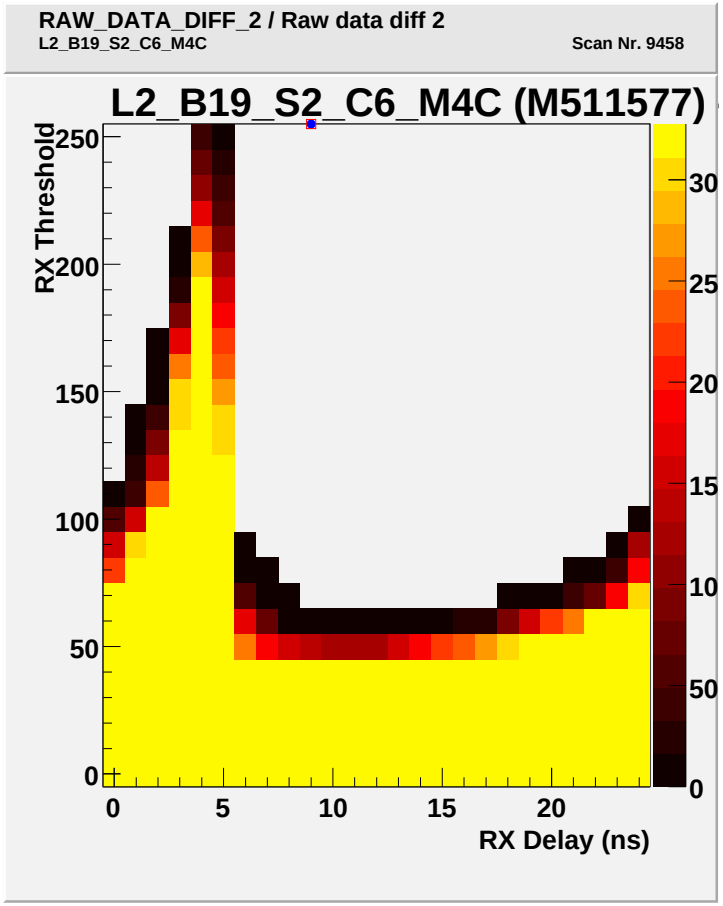
- Procedure is steered by a single GUI.
- Starts scans on 9 SBCs in the readout crates.
- DSPs on the RODs get the module data, make histograms and perform fits if needed.
- The result histograms are downloaded to memory and written to disk.



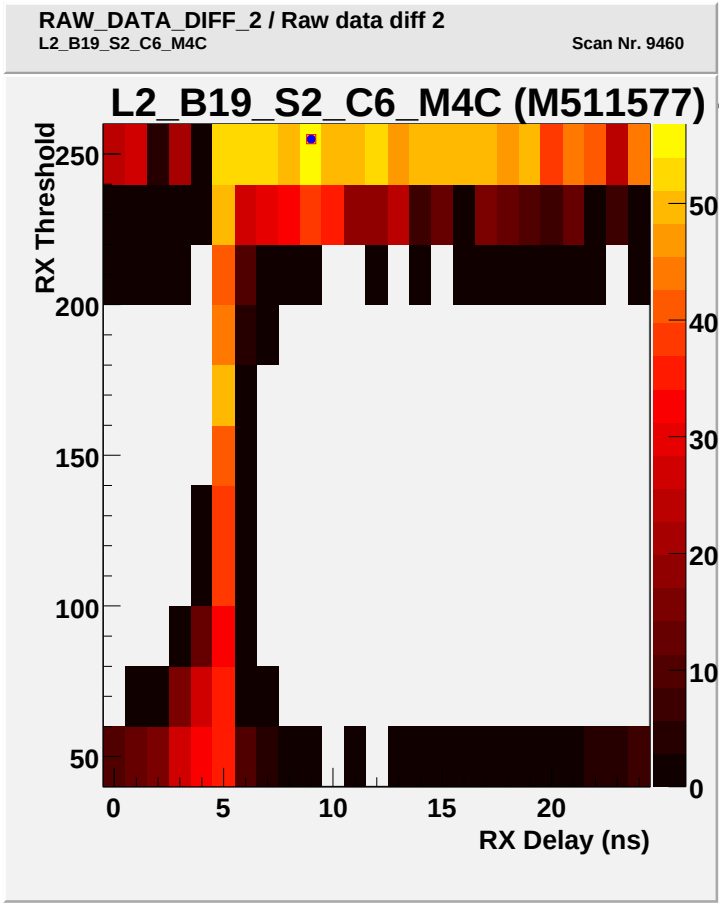
- Automatic analyses run to verify that calibration was successful.

Optolink Tuning

- The optical uplink needs to be tuned by adjusting:
  - The power of the on-detector lasers.
  - The PIN current threshold of the off-detector PIN diode.
  - The delay of the off-detector sampling clock.
- Several ways to tune optolink parameters. Currently, all of them ask the modules to send a 20 MHz clock pattern (algorithms using other patterns are in preparation).
- 96 % of the modules have been successfully tuned.
- Typical problems: Temperature dependence, clock pattern not representative, tuning algorithm mistunes special cases.
- Running and optotune on the full system takes $\sim$ 1 hour. Understanding if the tune was ok takes (from experience) longer.

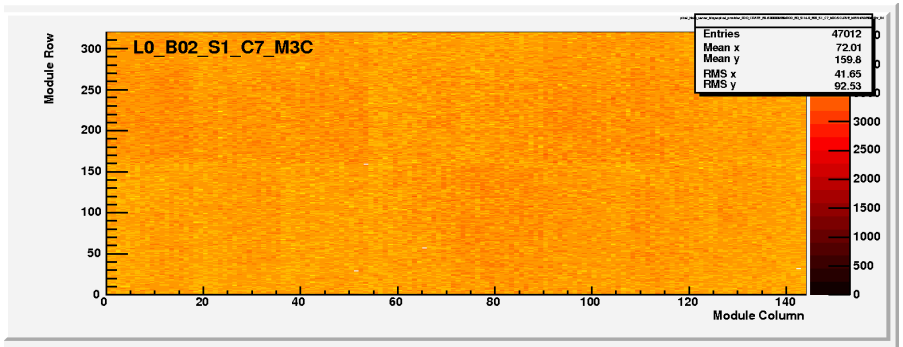


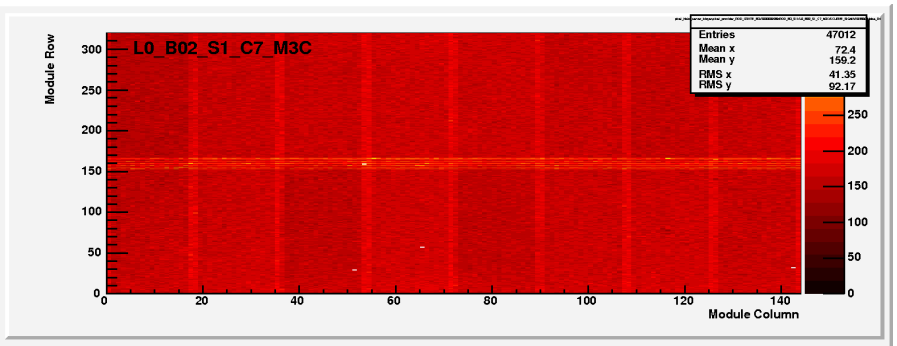
Error rate when sending a 20 MHz clock pattern.

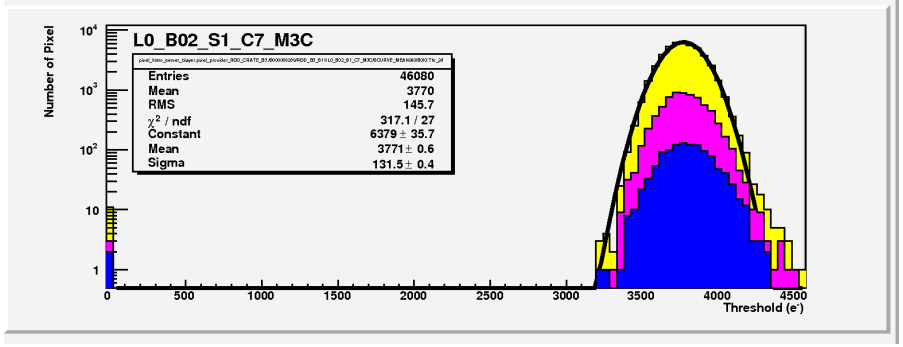


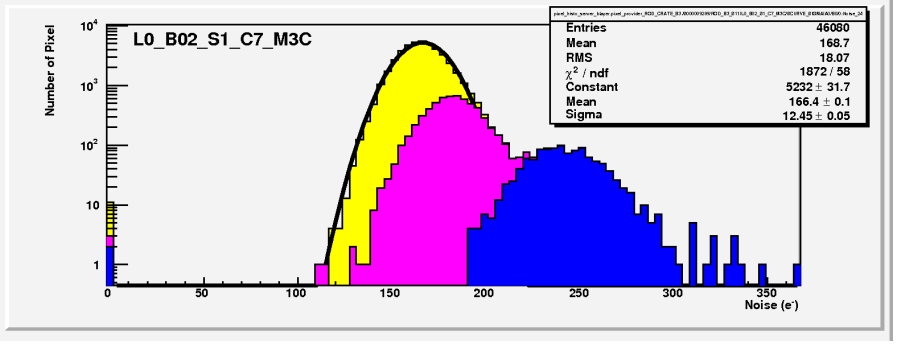
Error rate when sending a pseudo-random data pattern.

Threshold Determination

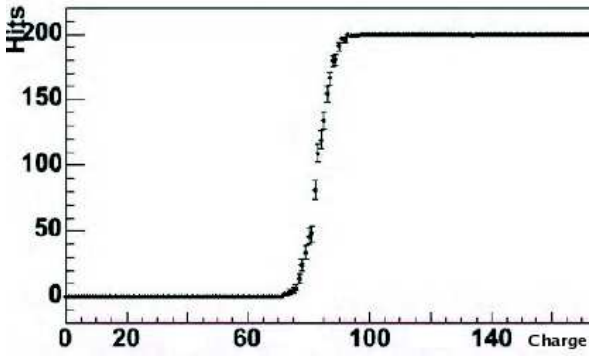






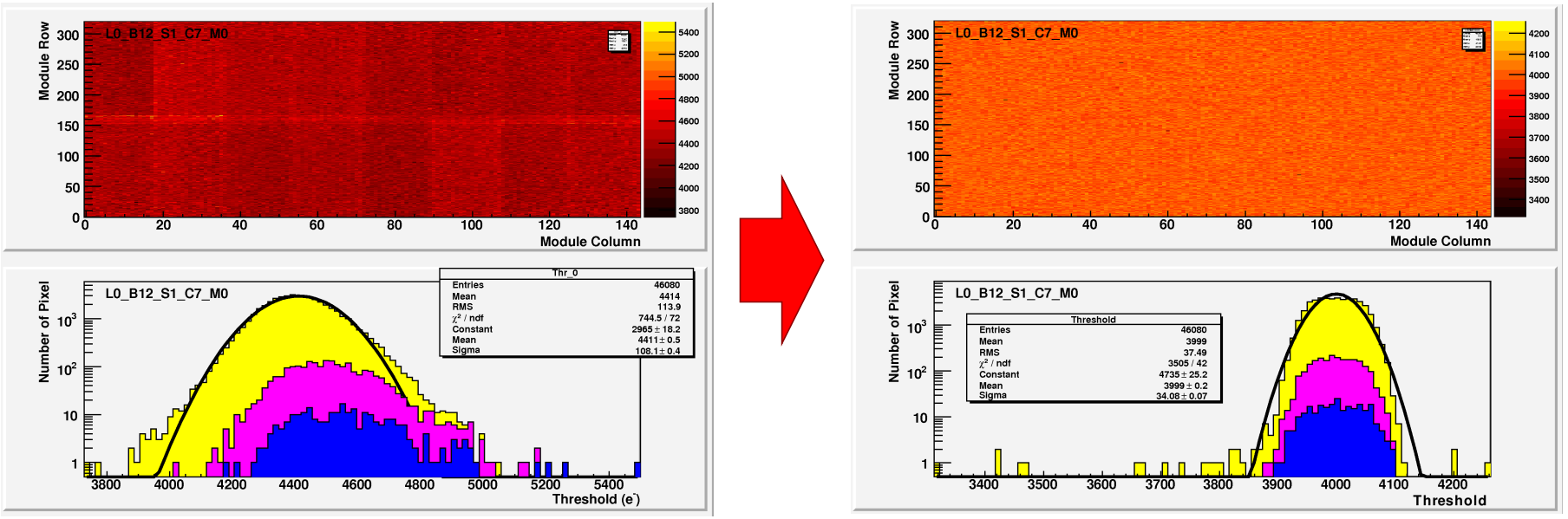


- Inject a range of charges is each pixel.
- Fit ERF to the number of events vs charge
  - extract threshold mean and sigma.



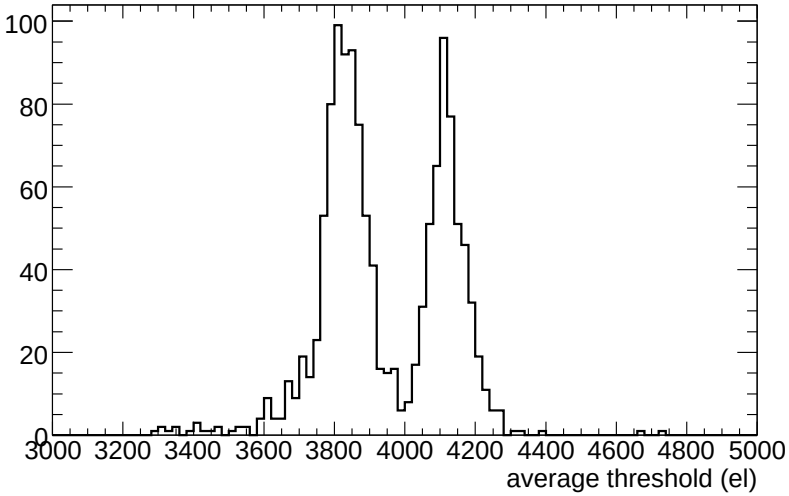
- Takes 1.5 hours to run on full detector. Have done 85 % so far.

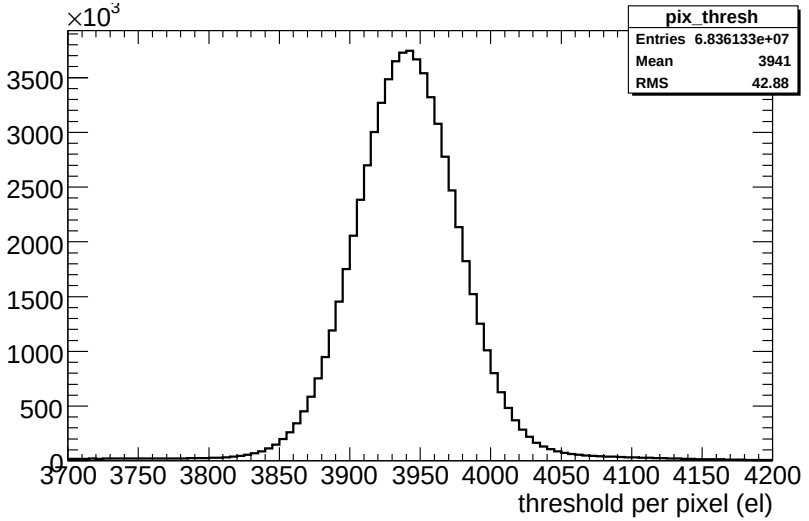
Threshold Tuning



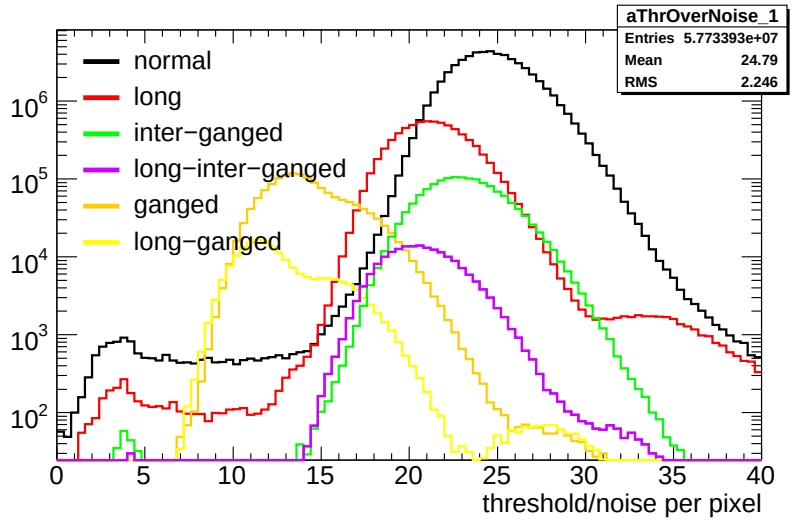
- Reduces threshold dispersion from $\sim$ 100 to $\sim$ 40 electrons.
- Have been using production tunings (left plot) for first cosmics.
- Detector has been tuned in the last few days.

Performance of Current Threshold Tuning



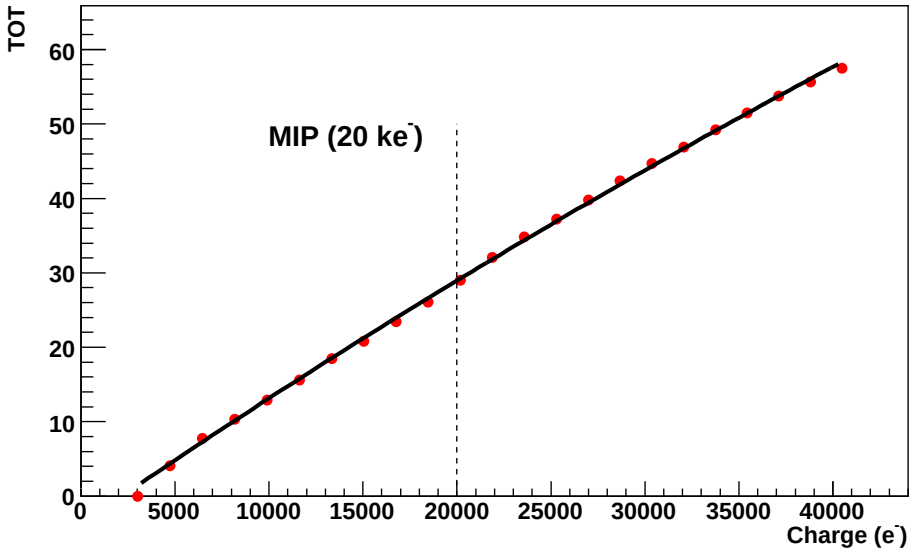


- Module production differ by institute → double peak.
- New tuning gives a threshold dispersion of 40 electrons.
- Threshold-over-noise for most pixels is ~ 25.

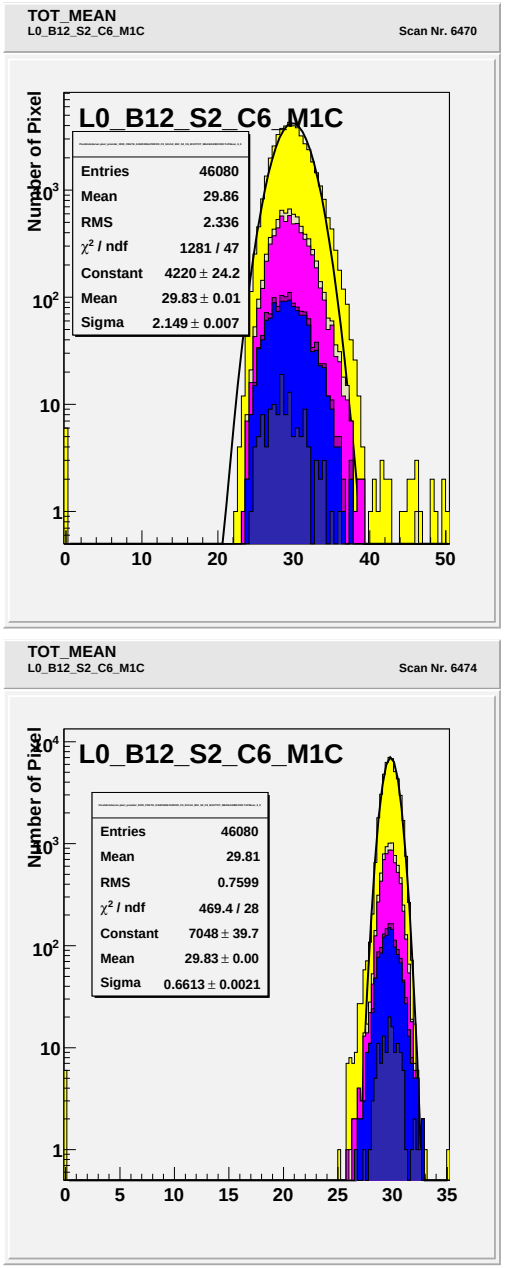


TOT Tuning and Calibration

- Adjust feedback current until a MIP (20 ke) corresponds to a TOT of 30.
- Extract full TOT-vs-charge calibration curve.

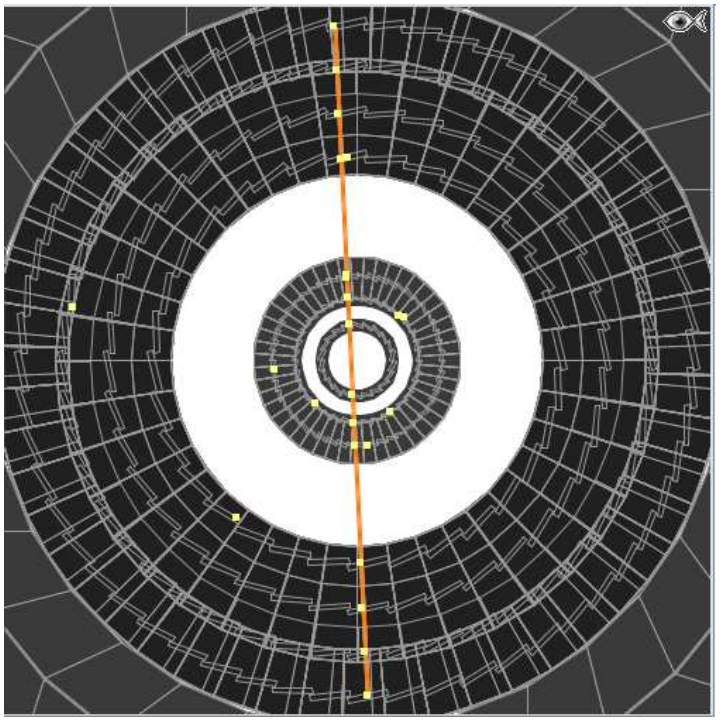


Tuning



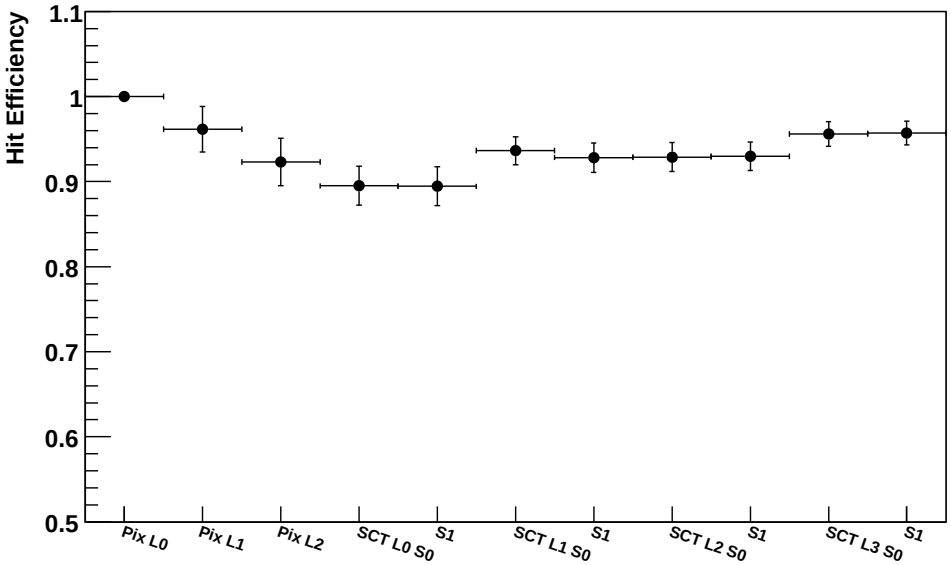
Cosmics Data Taking

- Joined combined running for the first time on Sept 4th. Wrong timing, no pixel hits on tracks.
- Sept 10th first beam through ATLAS.
- Second try on Sept 14th.
  New timing, read out 8 BCs.
  There are tracks!
- Same day we could already run stably for O(hours).



- Hundreds of tracks have been collected and many offline studies are ongoing. First alignment done (see talk by H. Gray).
- 95 % of the modules participate stably in data taking.
- Major reason for module disabling is optical problems.

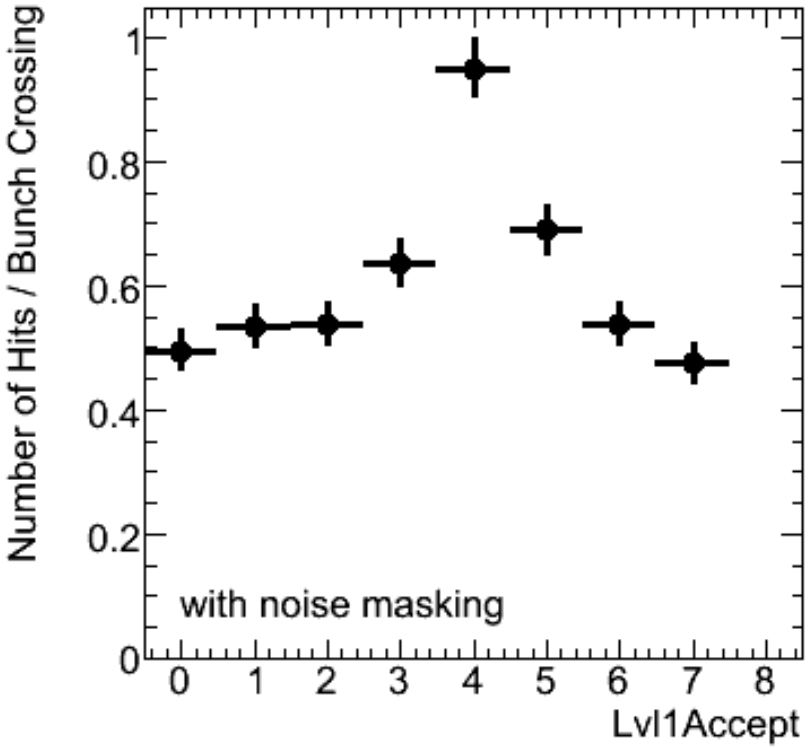
Hit Efficiencies



- The pixel barrel layers correspond to the left three points on plot.
- Hit efficiency is > 90 % in all three layers.

- Alignment will further improve the hit efficiency.
  But cannot (most likely) explain the whole efficiency loss.
- More statistics will help in understanding.

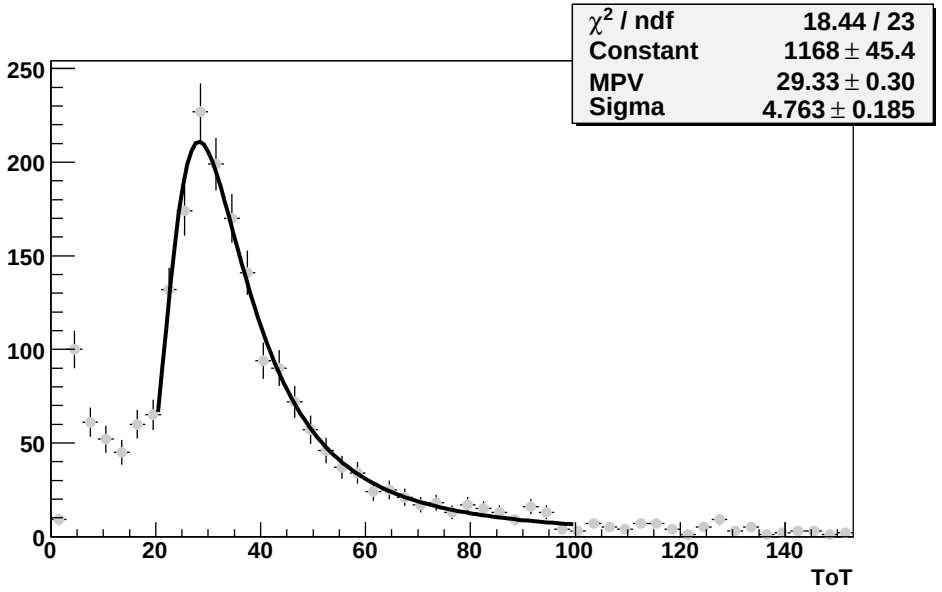
Occupancy



- The average number of noise hits in the detector per bunch crossing is $\sim$ 0.5!
- This corresponds to a per pixel noise occupancy of $5 \cdot 10^{-9}$.
- Even without selecting hits on tracks there is a clear peak from physics at LvL1Accepts 3, 4 and 5.

- Mask $\sim$ 5000 noisy pixels online (0.006 %).

TOT Distributions



Clusters on tracks

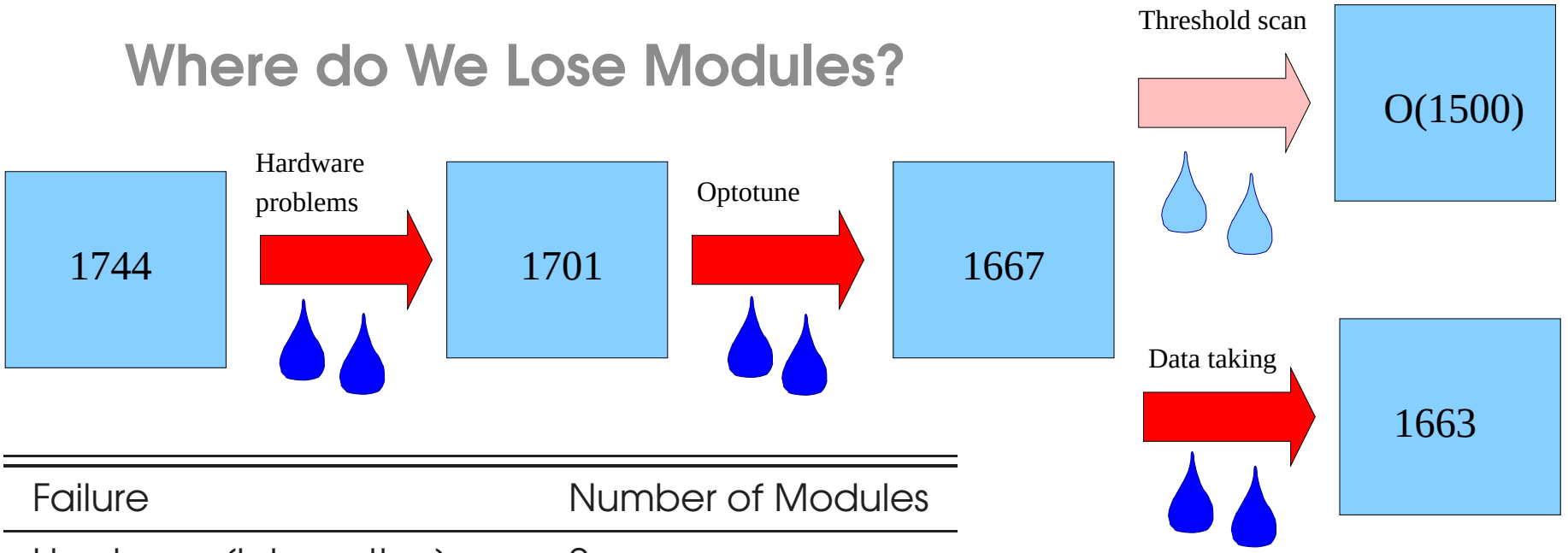
- Clusters on tracks for 4 cosmic runs.
- The cluster TOT peaks nicely at 30 which is the expected TOT for a MIP.
- Some noise clusters are associated to tracks, seen at low TOT.

- TOT distributions need to be studied as a function of the cluster charge, eta of the track and so on.
- Production TOT tunings seems a good enough starting point.

Summary

- Pixel detector got installed in June 2007 and connected in Spring 2008.
- Cooling plant failure delayed the commissioning until August 2008. After that, 5 week calibration program.
- Joined ATLAS cosmics data taking one week ago. Already timed in with the rest of ATLAS and collected hundreds of tracks.
- First alignment already made using these tracks.
- All pixel layers have $>$ 90% hit efficiency.
- 5% of modules disabled, most due to optical link problems.

Where do We Lose Modules?



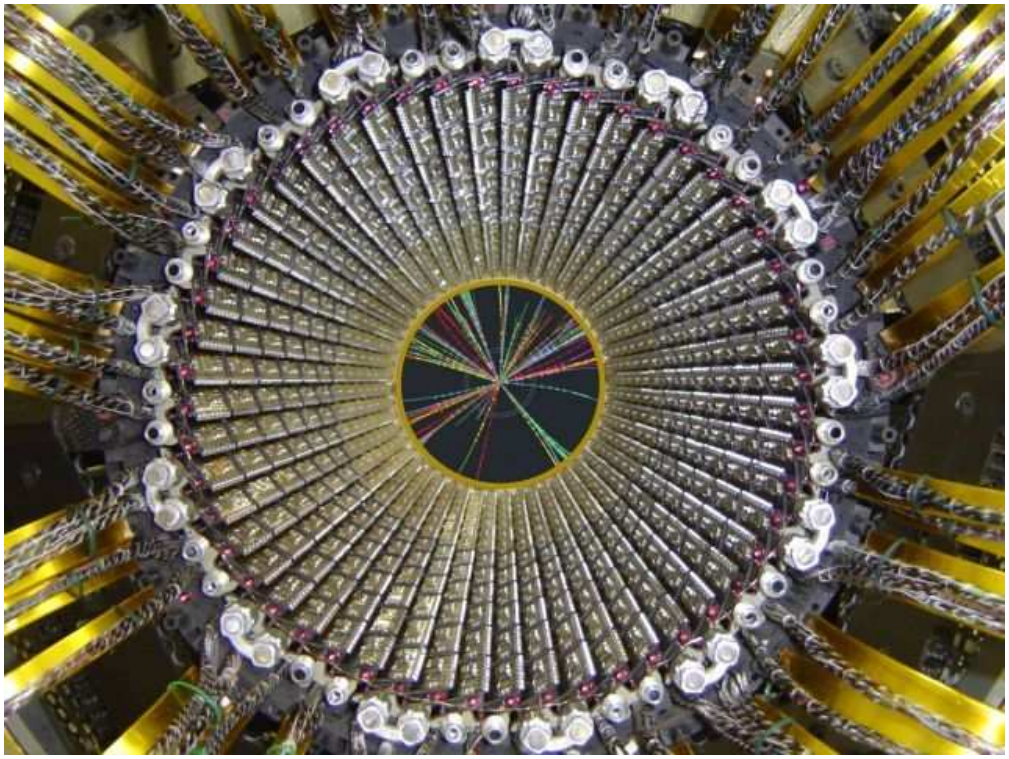
Failure	Number of Modules
Hardware (integration)	2
No high voltage	6
Downlink lasers	20
Non-standard currents etc	12
Not configurable	3
Bad optotune	34
Errors in data taking	4

Loss in threshold scan step is mostly due to features in calibration framework.
$\Rightarrow$ Will improve.

Outlook

- Finish the calibration program for all modules.
- Understand and solve problems with optolink tuning.
- Need to make sure we understand all aspects of our data.

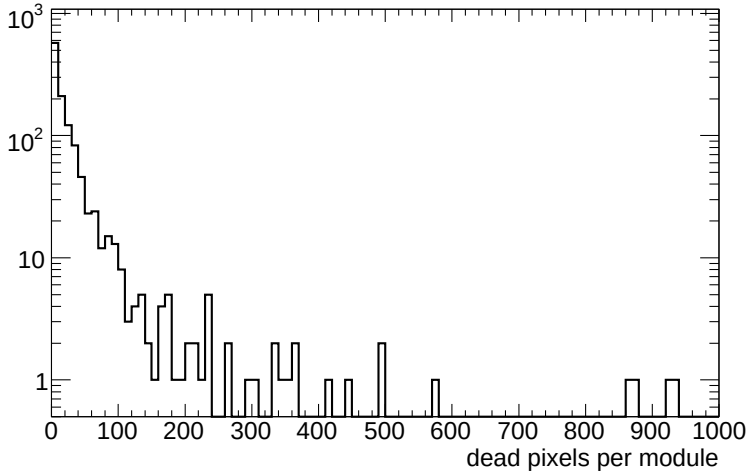
- Strategy for first beam was and is HV off and preamplifiers killed.
- So pixel detector has not seen beam in an active state.
- Let's see what beam and collisions will bring us!



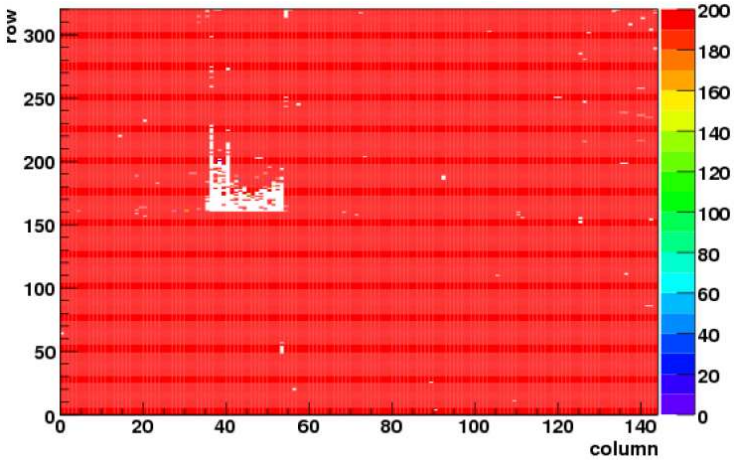
Backup Slides

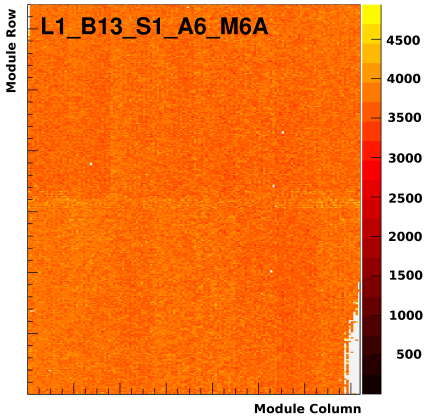
Dead and Noisy Pixels

- Bad pixels per module < 50 (0.1 %) for majority.
- Mask 5000 noisy pixels in data taking.



- Some modules with merged and disconnected bump bonds.

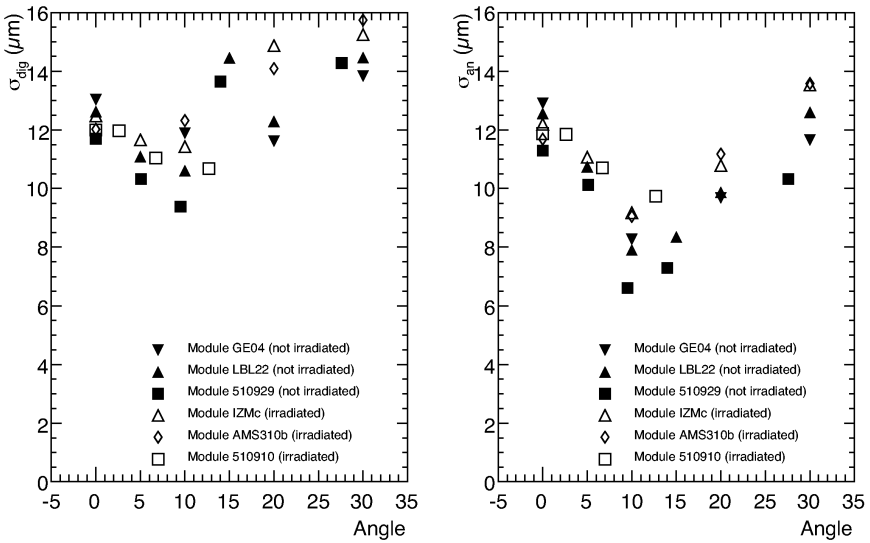




- Left plot: Region with disconnected bumps.
- Right plot: Region with merged bumps.

Hit Resolutions

- General rule: $\sigma = \text{pitch}/\sqrt{12}$.
- Pixel size 50×400 μm $\Rightarrow$
  - $\sigma_x = 14$ μm.
  - $\sigma_y = 115$ μm.



- Overlap residuals measured in cosmic data.
- $\sigma = \sigma_{overlap}/\sqrt{2}$.